A Phenomenological Model of the Baryons

The Body Center Cubic Model of the Vacuum Material

Jiao Lin Xu

The Center for Simulational Physics, The Department of Physics and Astronomy

University of Georgia, Athens, GA 30602, U. S. A.

E- mail: Jxu@Hal.Physast.Uga.edu

Abstract

From the quark confinement idea, we conjecture that the quarks compose colorless particles (uud and udd - the **Lee Particles**) and then the Lee Particles construct a body center cubic lattice in the vacuum. In terms of the energy band theory, from the symmetries of the body center cubic periodic field, we deduce the baryon spectrum (with **a united mass formula**) using only **2 flavored quarks** u and d. We also predict some new baryons: $\Lambda^0(2559)$, $\Lambda_C^+(6659)$, $\Lambda_b^0(10159)$.... The experiments to find the long lifetime baryon $\Lambda^0(2559)$ should be done first.

I Introduction

The Quark Model [1] has already explained the baryon spectrum in terms of quarks. It successfully gives intrinsic quantum numbers (I, S, C, b, and Q) of all baryons. However, (1) it has not given a satisfactory mass spectrum of baryons in a united mass formula [2]; (2) it needs too many elementary particles (6 flavors $\times$ 3 colors $\times$ 2 (quark and antiquark) = 36 quarks) [3] [4]; (3) the quantum numbers of the quarks are "entered by hand" [5] [6]; (4) on one hand it assumes [1] that all quarks (u, d, s, c, b, t) are independent elementary particles, but on the other hand it assumes that the higher energy quarks can decay into lower energy quarks [7], the two "hands" do not cooperate with each other; (5) all free quark searches since 1977 have had negative results [8]. Just as T. D. Lee pointed out [9]: "In order to apply the present theories, we need about seventeen ad hoc parameters. All these theories are based on symmetry considerations, yet most of the symmetry quantum numbers do not appear to be conserved. All hadrons are made of quarks and yet no single quark can be individually observed. Now,fifty years after the beginning of modern particle physics, our successes have brought us to the deeper problems. We are in a serious dilemma about how to make the next giant step. Because the challenge is related to the very foundation of the totality of physics, a breakthrough is bound to bring us a profound change in basic science." This paper trys to find a solution to the above problems.

Twenty years ago, T. D. Lee had already pointed out [5] : "we believe our vacuum, though Lorentz invariant, to be quite complicated. Like any other physical medium, it can carry long-range-order parameters and it may also undergo phase transitions... ." Recently, Frank Wilczek, the J. Robert Oppenheimer Professor at the Institute for Advanced Study in Princeton, further elaborated Lee's idea [10]: "empty space–the vacuum–is in reality a richly structured, though highly symmetrical, medium. Dirac's sea was an early indication of this feature, which is deeply embedded in quantum field theory and the Standard Model. Because the vacuum is a complicated material governed by locality and symmetry, one can learn how to analyze it by studying other such materials–that is, condensed matter." Professor Wilczek not only pointed out one of the most important and most urgent research directions of modern physics–studying the structure of the vacuum, but also provided a very practical and efficient way for the study–learning from studying condensed matter. Applying the Lee-Wilczek idea, this paper conjectures a structure of the vacuum (body center cubic symmetry), which will be used as the mechanism to generate the baryon spectrum [11].

According to Dirac's sea concept [12], there are follow Dirac seas: electron sea, μ lepton sea, τ lepton sea, u quark sea, d quark sea, s quark sea, c quark sea, b quark sea...in the vacuum. All of these Dirac seas are in the same space, at any location, that is, at any physical space point. **The facts (all hadrons are made of quarks and no single quark can be individually observed) imply that the quarks are confined in hadrons in the vacuum.** According to quantum chromodynamics [13], there are **super-strong color attractive interactions** among the quarks, causing three quarks of different colors to be confined together and form a colorless baryon (p, n, Λ, Σ, Ξ, Ω..) in the vacuum. These baryons, electrons, leptons, etc. will interact with one another and form the perfect vacuum material. However, some kinds of particles do not play an important role in forming the vacuum material. First, the main force which makes and holds the structure of the vacuum material must be the strong interactions, not the weak-electromagnetic, or the gravitational interactions. Hence, in considering the structure of the vacuum material, we leave out the Dirac seas of those particles which do not have strong interactions (e, μ, τ). Secondly, it is unlikely that the super stable vacuum material is composed of unstable blocks (the unstable baryons are short lived), hence we also omit the unstable particles (such as: Λ, Σ, Ξ, Ω, ...). Finally, there are only two kinds of possible particles left: the vacuum state protons (uud-**charged Lee Particle** [5] [9] [14] [15]) and the vacuum state neutrons (udd-**neutral Lee Particle**). It is well known that there are strong attractive forces between the protons and the neutrons inside a nucleus. Similarly, there should also exist strong attractive forces between the Lee Particles which will make and hold the densest structure of the vacuum state Lee Particles.

According to solid state physics [16], if two kinds of particles (with radius $R_1 < R_2$) satisfy the condition $1 > R_1/R_2 > 0.73$, the densest structure is the body center cubic crystal [17]. According to the Quark Model, the charged Lee Particle (uud) and the neutral Lee Particle (udd) are not completely the same, thus $R_1 \neq R_2$; and they are similar to each other, thus $R_1 \approx R_2$. Hence, if $R_1 < R_2$ (or $R_2 < R_1$), we have $1 > R_1/R_2 > 0.73$ (or $1 > R_2/R_1 > 0.73$). Therefore, we conjecture that the vacuum state Lee Particles construct the densest structure-**a body center cubic lattice** (in this paper it will be regarded as **the BCC model**) in the vacuum.

Similar to a crystal which has a periodic field, there are also periodic fields in the vacuum. From energy band theory [18] and the phenomenological fundamental hypotheses of the BCC model, we can deduce all intrinsic quantum numbers of all baryons which are consistent with the experimental results [19]. Likewise, we can calculate the masses of all baryons which are in very good agreement with the experimental results [19] using **a united mass formula**.

The vacuum material works like an **ultra-superconductor**. Since the energy gaps are so large (for electron the energy gap is about 0.5 Mev; for proton and neutron the energy gaps are about 939 Mev), there is no electric and mechanical resistance to any particle and any physical body (made by protons, neutrons, and electrons) moving inside the vacuum material with constant velocity.

II Fundamental Hypotheses

For simplicity, the intrinsic structure (three quarks) of baryons will be ignored temporarily. The baryons are treated as elementary particles in the phenomenological BCC model. We would like to call this simplification **the point baryon approximation**. The approximation is based on the the quark confinement theory [20] and the experimental results [8] that a baryon always appears as a whole particle.

In order to explain our model accurately and concisely, we will start from the phenomenological fundamental hypotheses in an axiomatic form.

Hypothesis I *There are only two kinds of fundamental quarks u and d in the quark family. There exist super-strong color attractive interactions between the colored quarks. Three quarks (uud or udd) compose a kind of colorless Fermi particles* ***in the vacuum state****. We call the particles the* ***Lee pareticles*** *[5] [9] [14] [15].*

According to the Quark Model [1], the Lee Particles are unflavored ($S = C = b = 0$) with spin $s = 1/2$ and isotropic spin $I = 1/2$. The excited (from the vacuum) free Lee Particles have

$$\begin{array}{lll} uud & \text{B=1, S=C=b=0, s=1/2, I=1/2, I}_z\text{= 1/2} & \textit{proton} \\ udd & \text{B=1, S=C=b=0, s=1/2, I=1/2, I}_z\text{= -1/2} & \textit{neutron} \end{array} \tag{1}$$

Hypothesis II *There are strong attractive interactions between the Lee Particles, and the interactions will make and hold the densest structure of the Lee Particles -* ***the body center cubic Lee Particle Lattice in the vacuum.*** *The lattice forms a strong interaction periodic field with body center cubic symmetries in the vacuum, where the periodic constant* a_x *is much smaller than the magnitude of the radii of the nuclei.*

Hypothesis III *Quantum mechanics applies to the ultra-microscopic world [21]. Thus, the energy band theory [18] is also valid in the ultra-microscopic world.* ***The energy band excited states of the Lee Particles will be various baryons****.*

According to the energy band theory, an excited Lee Particle (from vacuum), inside the body center cubic periodic field, will be in a state of the energy bands (a point of the Brillouin zone). **The first Brillouin zone** [22] of the body center cubic lattice is shown in Fig. 1. In Fig. 1 (depicted from [18] (Fig. 1) and [22](Fig. 8.10)), the (ξ, η, ζ) coordinates of the symmetry points are:

$$\begin{aligned} &\Gamma = (0,\ 0,\ 0),\ \ H = (0,\ 0,\ 1),\ \ P = (1/2,\ 1/2,\ 1/2), \\ &N = (1/2,\ 1/2,\ 0),\ \ M = (1,\ 0,\ 0), \end{aligned} \tag{2}$$

and the (ξ, η, ζ) coordinates of the symmetry axes are:

$$\begin{aligned} \Delta &= (0,\ 0,\ \zeta),\ \ 0 < \zeta < 1; \qquad \Lambda = (\xi,\ \xi,\ \xi),\ \ 0 < \xi < 1/2; \\ \Sigma &= (\xi,\ \xi,\ 0),\ \ 0 < \xi < 1/2; \quad D = (1/2,\ 1/2,\ \xi),\ \ 0 < \xi < 1/2; \\ G &= (\xi,\ 1\text{-}\xi,\ 0),\ \ 1/2 < \xi < 1; \quad F = (\xi,\ \xi,\ 1\text{-}\xi),\ \ 0 < \xi < 1/2. \end{aligned} \tag{3}$$

From Fig. 1, we know that the axis $\Delta(\Gamma - H)$ is a 4-fold rotation axis, the axis $\Lambda(\Gamma - P)$ is a 3-fold rotation axis, and the axis $\Sigma(\Gamma - N)$ is a 2-fold rotation axis.

Hypothesis IV *Due to the effect of the periodic field, fluctuations of an excited Lee Particle state may exist. Thus, the fluctuations of energy ε and intrinsic quantum numbers (such as the strange number S) may also exist. The fluctuation of the Strange number, if exists, is always $\Delta S = \pm 1$ [23]. From the fluctuation of the Strange number, we will be able to deduce new quantum numbers, such as the **Charmed number** C and the **Bottom number** b.*

Hypothesis V *The energy band excited states (except for the energy bands in the first Brillouin zone) of the Lee Particles are the unstable baryons (we call all baryons except protons and neutrons **unstable baryons**). Their quantum numbers and masses are determined as follows (note: the quantum numbers of the ground energy bands in the first Brillouin zone are determind by **Hypothesis I**):*

1. Baryon number B: according to **Hypothesis I**, all energy band states have

$$B = 1. \tag{4}$$

2. Isospin number I: the maximum isospin I_m is determined by the energy band degeneracy d [18], where

$$d = 2I_m + 1, \tag{5}$$

and another possible isospin value is determined by

$$I = I_m - 1, \quad I \geq 0. \tag{6}$$

In some cases the degeneracy d should be divided into sub-degeneracies before using the formulas. Specifically, if the degeneracy d is larger than the rotary fold

R of the symmetry axis:

$$d > R, \tag{7}$$

then we assume that the degeneracy will be divided into γ sub-degeneracies, where

$$\gamma = d/R. \tag{8}$$

3. Strange number S: the Strange number S is determined by the rotary fold R of the symmetry axis [18] with

$$S = R - 4, \tag{9}$$

where the number 4 is the highest possible rotary fold number. From Eq. (9) and Fig. 1, we get

$$\begin{array}{l} \Delta(\Gamma - H) \text{ is a 4-fold rotation axis, } R = 4 \rightarrow S = 0; \\ \Lambda(\Gamma - P) \text{ is a 3-fold rotation axis, } R = 3 \rightarrow S = -1; \\ \Sigma(\Gamma - N) \text{ is a 2-fold rotation axis, } R = 2 \rightarrow S = -2. \end{array} \tag{10}$$

For the other three symmetry axes $D(P - N)$, $F(P - H)$, and $G(M - N)$, which are on the surface of the first Brillouin zone (see Fig. 1), we determine the strange numbers as follows:

$$\begin{array}{l} D(P - N) \text{ is parallel to axis } \Delta,\ S_D = S_\Delta = 0; \\ F \text{ is parallel to an axis equivalent to } \Lambda,\ S_F = S_\Lambda = -1; \\ G \text{ is parallel to an axis equivalent to } \Sigma,\ S_G = S_\Sigma = -2. \end{array} \tag{11}$$

4. Electric charge Q: after obtaining B, S and I, we can find the charge Q from the Gell-Mann-Nishijiman relationship [24]:

$$Q = I_z + 1/2(S + B). \tag{12}$$

5. Charmed number C and Bottom number b: Since the Lee Particles do not have any partial charge and the unstable baryons are the energy band excited states

of the Lee Particles (see **Hypothesis III**), the unstable baryons shall not have partial charges. Thus, **if a partial charge is resulted from (9) and (12)**, we have to consider fluctuation (see **Hypothesis IV**). The formula (9) shall be changed into

$$\bar{S} = R - 4. \tag{13}$$

From **Hypothesis IV ($\Delta S = \pm 1$),** the real value of S is

$$S = \bar{S} + \Delta S = (R - 4) \pm 1. \tag{14}$$

The "Strange number" S in (14) is not completely the same as the strange number in (9). In order to compare it with the experimental results, we would like to give it a new name under certain circumstances. Based on **Hypothesis IV**, the new names will be the **Charmed** number and the **Bottom** number:

if $S = +1$ which originates from the fluctuation $\Delta S = +1$,
then we call it the **Charmed** number C ($C = +1$); (15)

if $S = -1$ which originates from the fluctuation $\Delta S = +1$,
and if there is an energy fluctuation,
then we call it the **Bottom** number b ($b = -1$). (16)

Thus, (12) needs to be generalized to

$$Q = I_z + 1/2(B + S_G) = I_z + 1/2(B + S + C + b), \tag{17}$$

where we define the generalized strange number as

$$S_G = S + C + b. \tag{18}$$

6. Charmed strange baryon Ξ_C and Ω_C: if the energy band degeneracy d is larger than the rotary fold R, the degeneracy will be divided. Sometimes degeneracies should be divided more than once. After the first division, the sub-degeneracy energy bands have $S_{Sub} = \bar{S} + \Delta S$. For the second division of a degeneracy bands, we have:

$$\begin{array}{l} \text{if the second division has fluctuation } \Delta S = +1, \\ \text{ then } S_{Sub} \text{ may be unchanged and we may have} \\ \text{ a Charmed number } C \text{ from } C = \Delta S = +1. \end{array} \tag{19}$$

   Therefore, we can obtain charmed strange baryons Ξ_C and Ω_C.

7. We assume that a baryon's static mass is the minimum energy of the energy curved surface which represents the baryon.

III The Energy Bands

Since the Lee Particle is a Fermion, its motion equation should be the Dirac equation. Taking into account that (according to the renormalization theory [25]) the bare mass of the Lee Particle shall be infinite (much larger than the empirical values of the baryon masses), we use the Schrödinger equation instead of the Dirac equation (our results will show that this is a very good approximation):

$$\frac{\hbar^2}{2m_b}\nabla^2\Psi + (\varepsilon - V(\vec{r}))\Psi = 0, \tag{20}$$

where $V(\vec{r})$ denotes the strong interaction periodic field with body center cubic symmetries and m_b is the bare mass of the Lee Particle.

Using the energy band theory [18] and the free particle approximation [26] (taking $V(\vec{r}) = V_0$ constant and making the wave functions satisfy the body center cubic periodic symmetries), we have [27]

$$\frac{\hbar^2}{2m_b}\nabla^2\Psi + (\varepsilon - V_0)\Psi = 0, \tag{21}$$

where V_0 is a constant potential. The solution of Eq.(21) is a plane wave

$$\Psi_{\vec{k}}(\vec{r}) = \exp\{-i(2\pi/a_x)[(n_1 - \xi)x + (n_2 - \eta)y + (n_3 - \zeta)z]\}, \tag{22}$$

where the wave vector $\vec{k} = (2\pi/a_x)(\xi, \eta, \zeta)$, a_x is the periodic constant, and n_1, n_2, n_3 are integers satisfying the condition (the result of the periodic symmetries of the body center cubic field)

$$n_1 + n_2 + n_3 = \pm \text{ even number or } 0. \tag{23}$$

Condition (23) implies that the vector $\vec{n} = (n_1, n_2, n_3)$ can only take certain values. For example, $\vec{n}$ can not take $(0, 0, 1)$ or $(1, 1, -1)$, but can take $(0, 0, 2)$ and $(1, -1, 2)$.

The zeroth-order approximation of the energy [26] is

$$\varepsilon^{(0)}(\vec{k}, \vec{n}) = V_0 + \alpha E(\vec{k}, \vec{n}), \tag{24}$$

$$\alpha = h^2/2m_b a_x^2, \tag{25}$$

$$E(\vec{k}, \vec{n}) = (n_1 - \xi)^2 + (n_2 - \eta)^2 + (n_3 - \zeta)^2. \tag{26}$$

Considering the symmetries of the body center cubic periodic field, the wave functions will satisfy the symmetries of the point group and space group of the BCC lattice, and the parabolic energy curve of the free Lee Particle will be changed to energy bands. The wave functions are not needed for the zeroth order approximation, so we only show the energy bands in Fig. 2-5. There are six small figures in Fig. 2-4. Each of them shows the energy bands in one of the six axes in Fig. 1. Each small figure is a schematic one where the straight lines that show the energy bands shold be parabolic curves. The numbers above the lines are the values of $\vec{n} = (n_1,\ n_2,\ n_3)$. The numbers under the lines are the fold numbers of the energy bands with the same energy (the zeroth order approximation). The numbers beside both ends of an energy band (the intersection of the energy band line and the vertical lines) represent the highest and lowest E($\vec{k}$,$\vec{n}$) values (see Eq. (26)) of the band. Putting the values of the E($\vec{k}$,$\vec{n}$) into Eq. (24), we get the zeroth order energy approximation values (in Mev).

IV The Recognition of the Baryons

According to **Hypothesis I**, the nucleons are the ground bands. Therefore, we can determine V_0 in formula (24), using the static masses (static energy) $M_{nucleon}$ of the nucleons. The static energy ($M_{nucleon}$ = 939 Mev [19]) of the nucleons should be the lowest energy (V_0) of the energy bands in (24). Thus, at the ground states, we have

$$\varepsilon^{(0)} = V_0 = M_{nucleon} = 939 \text{ Mev}. \tag{27}$$

Fitting the theoretical mass spectrum to the empirical mass spectrum of the baryons, we can also determine

$$\alpha = h^2/2m_b a_x^2 = 360 \text{ Mev} \tag{28}$$

in (24). Thus, we have

$$\varepsilon^{(0)}(\vec{k},\vec{n}) = V_0 + \alpha E(\vec{k},\vec{n}) = 939 + 360E(\vec{k},\vec{n}) \quad \text{(Mev)}. \tag{29}$$

Using **Hypothesis V** and the energy bands (Fig. 2-5), we can find the quantum numbers and masses of all excited energy bands. Then, from the quantum numbers and the masses we can recognize the **unstable baryons** [28]. As an example, we recognize the **unstable baryons** on the axis $\Delta(\Gamma - H)$.

The axis $\Delta(\Gamma - H)$ is a 4 fold rotary symmetry axis, $R = 4$. From (10), we get the strange number $S = 0$. For low energy levels, there are 8 and 4 fold degenerate energy bands and single bands on the axis. Since the axis has $R = 4$, from (7) and (8), the energy bands of degeneracy 8 will be divided into two 4 fold degenerate bands.

For **the 4 fold degenerate bands** (see Fig. 2(a) and Fig. 5(a)), using (5), we get the isospin $I_m = 3/2$, and using (12), we have $Q = 2,\ 1,\ 0,\ -1$. Comparing them with the experimental results [19] that the baryon families $\Delta(\Delta^{++}, \Delta^{+}, \Delta^{0}, \Delta^{-})$ have $S = 0$, $I = 3/2$, $Q = 2,\ 1,\ 0,\ -1$, we discover that each four fold degenerate band represents a baryon family Δ. Using (6), we get another $I = 3/2 - 1 = 1/2$, and from (12), we get $Q = 1,\ 0$. From the facts [19] that the baryon families $N(N^{+}, N^{0})$ have $S = 0$, $I = 1/2$, and $Q = 1,\ 0$, we know that there is another baryon family N corresponding to each Δ family. Using Fig. 2(a) and Fig. 5(a), we can get E_Γ, E_H, and $\vec{n}$ values. Then, putting the values of the E_Γ and E_H into the energy formula (29), we can find the values of the energy $\varepsilon^{(0)}$. Finally, we have

$$\begin{array}{llllll}
E_H = 1 & \vec{n} = (101,\text{-}101,011,0\text{-}11) & \varepsilon^{(0)} = 1299 & \Delta(1299); & N(1299) \\
E_\Gamma = 2 & \vec{n} = (110,1\text{-}10,\text{-}110,\text{-}1\text{-}10) & \varepsilon^{(0)} = 1659 & \Delta(1659); & N(1659) \\
E_\Gamma = 2 & \vec{n} = (10\text{-}1,\text{-}10\text{-}1,01\text{-}1,0\text{-}1\text{-}1) & \varepsilon^{(0)} = 1659 & \Delta(1659); & N(1659) \\
E_H = 3 & \vec{n} = (112,1\text{-}12,\text{-}112,\text{-}1\text{-}12) & \varepsilon^{(0)} = 2019 & \Delta(2019); & N(2019) \\
E_\Gamma = 4 & \vec{n} = (200,\text{-}200,020,0\text{-}20) & \varepsilon^{(0)} = 2379 & \Delta(2379); & N(2379) \\
E_H = 5 & \vec{n} = (121,1\text{-}21,\text{-}121,\text{–}1\text{-}21, & \varepsilon^{(0)} = 2739 & \Delta(2739); & N(2739) \\
 & \qquad 211,2\text{-}11,\text{-}211,\text{-}2\text{-}11) & \varepsilon^{(0)} = 2739 & \Delta(2739); & N(2739) \\
E_H = 5 & \vec{n} = (202,\text{-}202,022,0\text{-}22) & \varepsilon^{(0)} = 2739 & \Delta(2739); & N(2739) \\
E_H = 5 & \vec{n} = (013,0\text{-}13,103,\text{-}103) & \varepsilon^{(0)} = 2739 & \Delta(2739); & N(2739) \\
\ldots & & & &
\end{array} \tag{30}$$

From Fig. 2(a) and Fig. 5(b), we can see that there exist **single bands** on the axis Δ. From (5), we have $I = 0$. Using (9) and (12), we get $S = 0$ and $Q = 0+1/2(S+B) = 1/2$ (a partial charge). According to **Hypothesis V. 6**, we should use (14) instead of (9). Therefore, we have

$$S_{\text{Single}} = \bar{S}_\Delta \pm \Delta S = 0 \pm 1, \tag{31}$$

where $\Delta S = \pm 1$ from **Hypothesis IV**. The best way to guarantee the validity of Eq.(13)

in any small region is to assume that ΔS takes $+1$ and -1 alternately from the lowest energy band to higher ones. In fact, the $\vec{n}$ values are really alternately taking positive and negative values. Using the fact, we can find a phenomenological formula. If we define a function $Sign(\vec{n})$

$$Sign(\vec{n}) = \frac{n_1 + n_2 + n_3}{|n_1| + |n_2| + |n_3|} \ , \tag{32}$$

then the **phenomenological formula is**

$$\Delta S = -(1 + S_{axis})Sign(\vec{n}). \tag{33}$$

Before recognizing the baryons, we need to discuss the fluctuation of energy.

The fluctuation of the strange number will be accompanied by an energy change (**Hypothesis IV**). We assume that the change of the energy is proportional to (ΔS), a number $K \equiv 4 - R$ (R is the rotary number of the axis), and a number J representing the energy level with a **phenomenological formula:**

$$\Delta\varepsilon = \begin{Bmatrix} (-1)^K 100[(J-1) \times K - \delta(K)]\Delta S & J = 1,\, 2,\, ... \\ 0 & J = 0\ , \end{Bmatrix} \tag{34}$$

where $\delta(K)$ is a Dirac function ($\delta(K) = 1$ when $K = 0$, and $\delta(K) = 0$ when $K \neq 0$.), and J is the energy level number ($J = 0, 1,\, 2,\, 3,...$) with asymmetric $\vec{n}$ values (or with partial electric charge from (9) for single energy bands)

Due to the fluctuation, the energy formula (29) should be changed to

$$\begin{aligned} \varepsilon &= \varepsilon^{(0)}(\vec{\mathbf{k}}, \vec{\mathbf{n}}) + \Delta\varepsilon \\ &= \mathbf{939 + 360E}(\vec{\mathbf{k}}, \vec{\mathbf{n}}) + \Delta\varepsilon \ \ . \end{aligned} \tag{35}$$

The formula (35) is the united mass formula which can give the masses of all the baryons. It is worth while to emphasize **that the fluctuation of the energy**

is very small. For the most part of the baryons, the energy fluctuation is zero (such as (5)). The energy fluctuation is about 5 percent for single energy bands of the axis Δ and the axis Σ.

After obtaining the energy fluctuation formula, we come back to the study of the single bands on the axis Δ.

First, at $E_\Gamma = 0, J = 0, \varepsilon = 939$ from (35), the lowest energy band with $\vec{n} = (0, 0, 0)$ represents the baryon $N(939)$ from (1).

Then, at $E_H = 1$, the second lowest band with $\vec{n} = (0, 0, 2)$ and $J = 1$. From (33), $\Delta S = -1$. Thus $S = -1$, and $\Delta\varepsilon = 100$ Mev from (34)$\rightarrow$ the energy $\varepsilon = 1399$ Mev from (35), as well as $I = Q = 0$ from (12). Therefore, it represents the baryon $\Lambda(1399)$.

At $E_\Gamma = 4$, the band with $\vec{n} = (0, 0, -2)$, we get $\Delta S = +1$ from (33). Thus, $\mathbf{S = \bar{S}_\Delta + 1 = 1.}$ The energy $\varepsilon = 2279$ from (35) and (34). Here $S = +1$ originates from the fluctuation $\Delta S = +1$ and there is an energy fluctuation of $\Delta\varepsilon = -100$. From **Hypothesis V. 6 (15)**, we know the energy band has a charmed number $C = +1$. **It represents a new baryon with** $I = 0$, $C = +1$, and $Q = +1$. Since it has a charmed number $C = +1$, **we will call it the CHARMED baryon** $\Lambda_C^+(2279)$ [29]. It is very important to pay attention to **the Charmed baryon** $\Lambda_C^+(2279)$ **born here, on the single energy band, and from the fluctuation** $\Delta S = +1$ and $\Delta\varepsilon = -100$ Mev.

Continuing the above procedure, we have

$$
\begin{array}{llllll}
E_H = 1 & \vec{n} = (002) & \Delta S = -1 & J = 1 & \Delta\varepsilon = +100 & \Lambda(1399) \\
E_\Gamma = 4 & \vec{n} = (00\text{-}2) & \Delta S = +1 & J = 2 & \Delta\varepsilon = -100 & \Lambda_C^+(2279) \\
E_H = 9 & \vec{n} = (004) & \Delta S = -1 & J = 3 & \Delta\varepsilon = +100 & \Lambda(4279) \\
E_\Gamma = 16 & \vec{n} = (00\text{-}4) & \Delta S = +1 & J = 4 & \Delta\varepsilon = -100 & \Lambda_C^+(6599) \\
E_H = 25 & \vec{n} = (006) & \Delta S = -1 & J = 5 & \Delta\varepsilon = +100 & \Lambda(10039) \\
E_\Gamma = 36 & \vec{n} = (00\text{-}6) & \Delta S = +1 & J = 6 & \Delta\varepsilon = -100 & \Lambda_C^+(13799) \\
\ldots & & & & &
\end{array}
\tag{36}
$$

Continuing above procedure, we can find the whole baryon spectrum [28]. Our results are shown in Tables 1 though 6.

V Comparing Results

We compare the theoretical results of the BCC model to the experimental results [19] using Tables 1-6 [30]. In the comparison, we will use the following laws:

(1) We do not take into account the angular momenta of the experimental results. We assume that the small differences of the masses in the same group of baryons originate from their different angular momenta. If we ignore this effect, their masses should be essentially the same.

(2) We use the baryon name to represent the intrinsic quantum numbers as shown in the second column of Table 1.

(3) For low energy cases, the baryons from different symmetry axes with the same S, C, b, Q, I, I_Z, and $\overrightarrow{n}$ value, as well as in the same Brillouin zone are regarded as the same baryon. The mass of the baryon is the lowest value of their masses.

The ground states of various kinds of baryons are shown in Table 1. These baryons have a relatively long lifetime and are the most important experimental results of the baryons. From Table 1, we can see that all theoretical intrinsic quantum numbers (I, S, C, b, and Q) are the same as experimental results. Also the theoretical mass values are in very good agreement with the experimental values.

From Table 2-6, we can see that the intrinsic quantum numbers of the theoretical results are the same as the experimental results. Also the theoretical masses of the baryons are in very good agreement with the experimental results.

The theoretical results $N(1209)$ is not found in experiments. We guess that it is covered up by the experimental baryon $\Delta(1232)$. The reasons are as follows : (1) they are unflavored baryons with the same S = C = b =0 and Q ($Q_{N^+} = Q_{\Delta^+}$ and $Q_{N^0} = Q_{\Delta^0}$); (2) they have the same $\overrightarrow{n}$ values ($\overrightarrow{n}_{N(1209)} = (011, 101)$, $\overrightarrow{n}_{\Delta(1299)}$ = (101,-101,011,0-11)) and they are both in the second **Brillouin zone**; (3) the experimental width (120 Mev) of $\Delta(1232)$ is very large, and the baryon $N(1209)$ is fall within the width region of

$\Delta(1232)$; (4) the mass (1209 Mev) of $N(1209)$ is essentially the same as the mass (1232 Mev) of $\Delta(1232)$. The facts that the experimental value 1232 is much lower than the theoretical value 1299 of $\Delta(1299)$ and the experimental width (120) is much larger than other baryons (with similar masses) support the explanation.

In summary, the BCC model explains all baryon experimental intrinsic quantum numbers and masses. Virtually no experimentally confirmed baryon is not included in the model.

VI Predictions and Discussion

A Some New Baryons

According to the BCC model, a series of possible baryons exist. However, when energy goes higher and higher, on one hand, the theoretical energy bands (baryons) will become denser and denser; while on the other hand, the experimental full widthes of the baryons will become wider and wider. This makes the possible baryons extremely difficult to be separated. Therefore, currently it is very difficult to discover higher energy baryons predicted by the BCC model. We believe that many new baryons will be discovered in the future with the development of more sensitive experimental techniques. The following new baryons predicted by the model seem to have a better chance to be discovered in the not too distant future: $\Lambda^0(2559)$, $\Omega^-(3619)$, $\Lambda_b^0(10159)$, $\Lambda_C^+(6599)$, $\Xi_C(3169)$, $\Sigma_C(2969)$...

B Experimental Verification of the BCC Model

From Fig. 5 (c), we see three "brother" baryons: at $E_N = 1/2$, $\overrightarrow{n} = (1,1,0)$, $\Lambda(1119)$; at $E_N = 9/2$, $\overrightarrow{n} = (2,2,0)$, $\Lambda(2559)$; at $E_N = 25/2$, $\overrightarrow{n} = (3,3,0)$, $\Lambda_b(5639)$. They are born on the same symmetry axis Σ and at the same symmetry point N.

The three "brothers" have the same isospin I = 0, the same electric charge Q = 0, and the same generalized strange number (see (18)) S_G = S + C + b = -1. Among the three "brothers", the light one ($\Lambda(1119)$) and the heavy one ($\Lambda_b(5639)$) both have long lifetimes (τ = $2.6\times10^{-10}s$ for $\Lambda(1119)$, τ = $1.1\times10^{-12}s$ for $\Lambda_b(5639)$), but the middle one ($\Lambda(2559)$) has not been discovered. Thus, we propose that one search for the long lifetime baryon $\Lambda(2559)$ (I = 0, S = -1, Q = 0, M = 2559 Mev, and lifetime $2.6\times10^{-10}s > \tau > 1.1\times10^{-12}s$). The discovery of the baryon $\Lambda(2559)$ will provide a strong support for the BCC model.

C Discussions

1. From (28), we have $m_b a_x^2 = h^2/720$ Mev. Although we do not know the values of m_b and a_x, we find that $m_b a_x^2$ is a constant. According to the renormalization theory [25], the bare mass of the Lee Particle should be infinite, so that a_x will be zero. Of course, the infinite and the zero are physical concepts in this case. We understand that the "infinite" means m_b is huge and the "zero" means a_x is much smaller than the nuclear radius. "m_b is huge" guarantees that we can use the Schrödinger equation (20) instead of the Dirac equation, and "a_x is much smaller than the nuclear radius" makes the structure of the vacuum material very difficult to be discovered.

2. The BCC model presents not only a baryon spectrum, but also a reasonable explanation for the experimental fact that all baryons automatically decay to nucleons (p or n) in a very short time ($< 10^{-9}$ second). The reason is very simple: the baryons are energy band excited states of the Lee Particle, while the nucleons are the ground band states of the Lee Particles. It is a well known law in physics that the excited states will decay into the ground state.

3. After nuclear fusion energy was discovered, we understand the sun's energy. Similarly, the superconductor will help us explain the vacuum material. The vacuum

material is a super ideal superconductor.

VII Conclusions

1. Although baryons (Δ, N, Λ, Σ, Ξ, Ω, $\Lambda_{C,}$ Ξ_C, Σ_C, and Λ_b...) are so different from one another in I, S, C, b, Q, and M, they may be the same kind of particles (the Lee Particles), which are in different energy band states. The long life baryons $\Lambda(1116)$, $\Sigma(1193)$, $\Omega(1672)$, ... may be the metastable states.

2. The quantum number S, C, and b may not come from the quarks (s, c, b), they may be from symmetries of the body center cubic periodic field. Frank Wilczek pointed out in Reviews of Modern Physics [31]: Some "appropriate symmetry principles and degrees of freedom, in terms of which the theory should be formulated, have not yet been identified." We believe that the body center cubic periodic symmetry of the vacuum material may be "the appropriate symmetry".

3. There may be only 2 kinds of quarks (u and d), each of them has three colored members, in the quark family. The super-strong attractive forces (color) make the colorless Lee Particle (uud and udd) first. Then the Lee Particles constitute a body center cubic lattice in the vacuum.

4. Due to the existence of the vacuum material, all observable particles are constantly affected by the vacuum material (the Lee Particle lattice). Thus, some laws of statistics (such as fluctuation) can not be ignored.

5. **There is no other model which can deduce the full baryon spectrum using a united mass formula.**

6. Although the BCC model successfully explain the baryon spectrum, the baryon spectrum is deduced from 5 phenomenological Hypotheses and 3 phenomenological formulas in the BCC model. Thus, the BCC model is only a phenomenological model.

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FIGURES

Fig. 1. The first Brillouin zone of the body center cubic lattice. The the symmetry points and axes are indicated. The center of the first Brillouin zone is at the point Γ. The axis Δ is a 4 fold rotation axis, the strange number S = 0, the baryon family Δ (Δ^{++}, Δ^{+}, Δ^{0}, Δ^{-}) and N will appear on the axis. The axes Λ and F are 3 fold rotation axes, the strange number S = -1, the baryon family Σ (Σ^{+}, Σ^{0}, Σ^{-}) and Λ will appear on the axes. The axes Σ and G are 2 fold rotation axes, the strange number S = -2, the baryon family Ξ (Ξ^{0}, Ξ^{-}) will appear on the axes. The axis D is parallel to the axis Δ, S = 0. And the axis is a 2 fold rotation axis, the baryon family N (N^{+}, N^{0}) will be on the axis.

Fig. 2. (a) The energy bands on the axis Δ (the axis $\Gamma$$-$H). E_Γ is the value of E($\vec{k}$, $\vec{n}$) (see Eq. (26)) at the end point Γ, while E_H is the value of E($\vec{k}$, $\vec{n}$) at other end point H. (b) The energy bands on the axis Λ (the axis Γ-P). E_Γ is the value of E($\vec{k}$, $\vec{n}$) (see Eq. (26)) at the end point Γ, while E_P is the value of E($\vec{k}$, $\vec{n}$) at other end point P.

Fig. 3. (a) The energy bands on the axis Σ (the axis Γ-N). E_Γ is the value of E($\vec{k}$, $\vec{n}$) (see Eq. (26)) at the end point Γ, while E_N is the value of E($\vec{k}$, $\vec{n}$) at other end point N. (b) The energy bands on the axis D (the axis P-N). E_P is the value of E($\vec{k}$, $\vec{n}$) (see Eq. (26)) at the end point P, while E_N is the value of E($\vec{k}$, $\vec{n}$) at other end point N.

Fig. 4. (a) The energy bands on the axis F (the axis P-H). E_P is the value of E($\vec{k}$, $\vec{n}$) (see Eq. (26)) at the end point P, while E_H is the value of E($\vec{k}$, $\vec{n}$) at other end point H. (b) The energy bands on the axis G (the axis M-N). E_M is the value of E($\vec{k}$, $\vec{n}$) (see Eq. (26)) at the end point M, while E_N is the value of E($\vec{k}$, $\vec{n}$) at other end point N.

Fig. 5. (a) The 4 fold degenerate energy bands (selected from Fig. 2(a)) on the axis Δ (the axis Γ-H). (b) The single energy bands (selected from Fig. 2(a)) on the axis Δ (the axis Γ-H). (c) The single energy band (selected from Fig. 3(a)) on the axis Σ (the axis Γ-N).

TABLE

Table 1. The Ground States of the Various Baryons.

Theory	Quantum. No	Experiment	R	Life Time
Name(M)	S, C, b, I, Q	Name(M)		
p(939)	0, 0, 0, 1/2, 1	p(938)	0.1	$> 10^{31} years$
n(939)	0, 0, 0, 1/2, 0	n(940)	0.1	1.0×10^{8} s
$\Lambda(1119)$	-1, 0, 0, 0, 0	$\Lambda(1116)$	0.3	$2.6\times10^{-10}s$
$\Sigma(1209)^{+}$	-1, 0, 0, 1, 1	$\Sigma(1189)^{+}$	1.7	$.80\times10^{-10}s$
$\Sigma(1209)^{0}$	-1, 0, 0, 1, 0	$\Sigma(1193)^{0}$	1.4	$7.4\times10^{-20}s$
$\Sigma(1209)^{-}$	-1, 0, 0, 1, -1	$\Sigma(1197)^{-}$	1.0	$1.5\times10^{-10}s$
$\Xi(1299)^{0}$	-2, 0, 0, 1/2, 0	$\Xi(1315)^{0}$	1.2	$2.9\times10^{-10}s$
$\Xi(1299)^{-}$	-2, 0, 0, 1/2, -1	$\Xi(1321)^{-}$	1.7	$1.6\times10^{-10}s$
$\Omega(1659)^{-}$	-3, 0, 0. 0, -1	$\Omega(1672)^{-}$	0.8	$.82\times10^{-10}s$
$\Lambda_c^{+}(2279)$	0, 1, 0, 0, 1	$\Lambda_c^{+}(2285)$	0.3	$.21\times10^{-12}s$
$\Xi_c^{+}(2549)$	-1, 1, 0, 1/2, 1	$\Xi_c^{+}(2466)$	3.4	$.35\times10^{-12}$
$\Xi_c^{0}(2549)$	-1, 1, 0, 1/2, 1	$\Xi_c^{0}(2470)$	3.2	$.10\times10^{-12}s$
$\Sigma_c^{++}(2449)$	0, 1, 0, 1, 2	$\Sigma_c^{++}(2453)$	0.2	
$\Sigma_c^{+}(2449)$	0, 1, 0, 1, 1	$\Sigma_c^{+}(2454)$	0.2	
$\Sigma_c^{0}(2449)$	0, 1, 0, 1, 0	$\Sigma_c^{0}(2452)$	0.1	
$\Omega_c(2759)$	0, 0, -1, 0, 0	$\Omega_c(2704)$	2.0	$.64\times10^{-13}s$
$\Lambda_b(5639)$	0, 0, -1, 0, 0	$\Lambda_b(5641)$	.04	$1.1\times10^{-12}s$
$\Delta(1299)^{++}$	0, 0, 0, 3/2, 2	$\Delta(1232)^{++}$	5.2	Γ=120 Mev
$\Delta(1299)^{+}$	0, 0, 0, 3/2, 1	$\Delta(1232)^{+}$	5.4	Γ=120 Mev
$\Delta(1299)^{0}$	0, 0, 0, 3/2, 0	$\Delta(1232)^{0}$	5.4	Γ=120 Mev
$\Delta(1299)^{-}$	0, 0, 0, 3/2, -1	$\Delta(1232)^{-}$	5.4	Γ=120 Mev

In the fourth column, R $=(\frac{\Delta M}{M})\%$.

Table 2. The Unflavored Baryons N and Δ (S= C=b = 0)

Theory	Experiment	$\frac{\Delta M}{M}$%	Theory	Experiment	$\frac{\Delta M}{M}$%
$\bar{\mathbf{N}}$(**939**)	$\bar{\mathbf{N}}$(**939**)	**0.0**	$\bar{\Delta}$(**1254**)#	$\bar{\Delta}$(**1232**)	**1.8**
N(1479)	N(1440) N(1520) N(1535)				
$\bar{\mathbf{N}}$(**1479**)	$\bar{\mathbf{N}}$(**1498**)	**1.2**			
N(1659) N(1659)	N(1650) N(1675) N(1680) N(1700) N(1710) N(1720)		Δ(1659) Δ(1659)	Δ(1600) Δ(1620) Δ(1700)	
$\bar{\mathbf{N}}$(**1659**)	$\bar{\mathbf{N}}$(**1689**)	**1.7**	$\bar{\Delta}$(**1659**)	$\bar{\Delta}$(**1640**)	**1.2**
N(1839) N(1839) N(1929) N(1929) N(2019)	N(1900)∗ N(1990)∗ N(2000)∗ N(2080)∗		Δ(1929) Δ(1929) Δ(2019)	Δ(1900) Δ(1905) Δ(1910) Δ(1920) Δ(1930) Δ(1950)	
$\bar{\mathbf{N}}$(**1914**)	$\bar{\mathbf{N}}$(**1923**)	**0.5**	$\bar{\Delta}$(**1959**)	$\bar{\Delta}$(**1919**)	**2.1**
N(2199) N(2199)	N(2190) N(2220) N(2250)				
$\bar{\mathbf{N}}$(**2199**)	$\bar{\mathbf{N}}$(**2220**)	**0.9**			
N(2379) N(2549)			Δ(2379)	Δ(2420)	
N(2549) N(2559)			$\bar{\Delta}$(**2379**)	$\bar{\Delta}$(**2420**)	**1.6**
3N(**2649**)	**N**(**2600**)	**1.9**	Δ(2649)		
4N(2739)			5Δ(2739)		

#The average of N(1209) and Δ(1299).

*Evidences are fair, they are not listed in the Baryon Summary Table [19].

Table 3. Two Kinds of Strange Baryons Λ and Σ ($S = -1$)

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Lambda(\mathbf{1119})$	$\Lambda(\mathbf{1116})$	**0.36**	$\Sigma(\mathbf{1209})$	$\Sigma(\mathbf{1193})$	**1.4**
$\Lambda(1299)$ $\Lambda(1399)$					
$\bar{\Lambda}(\mathbf{1349})$	$\bar{\Lambda}(\mathbf{1405})$	**4.0**	$\Sigma(\mathbf{1299})$	$\Sigma(\mathbf{1385})$	**6.2**
$\Lambda(1659)$ $\Lambda(1659)$ $\Lambda(1659)$	$\Lambda(1520)$ $\Lambda(1600)$ $\Lambda(1670)$ $\Lambda(1690)$		$\Sigma(1659)$ $\Sigma(1659)$ $\Sigma(1659)$	$\Sigma(1660)$ $\Sigma(1670)$ $\Sigma(1750)$ $\Sigma(1775)$	
$\bar{\Lambda}(\mathbf{1659})$	$\bar{\Lambda}(\mathbf{1620})$	**2.4**	$\bar{\Sigma}(\mathbf{1659})$	$\bar{\Sigma}(\mathbf{1714})$	**3.2**
$\Lambda(1929)$ $\Lambda(1929)$ $\Lambda(1929)$	$\Lambda(1800)$ $\Lambda(1810)$ $\Lambda(1820)$ $\Lambda(1830)$ $\Lambda(1890)$		$\Sigma(1929)$ $\Sigma(1929)$	$\Sigma(1915)$ $\Sigma(1939)$	
$\bar{\Lambda}(\mathbf{1929})$	$\bar{\Lambda}(\mathbf{1830})$	**5.4**	$\bar{\Sigma}(\mathbf{1929})$	$\bar{\Sigma}(\mathbf{1928})$	**.05**
$\Lambda(2019)$ $\Lambda(2019)$	$\Lambda(2100)$ $\Lambda(2110)$		$\Sigma(\mathbf{2019})$	$\Sigma(\mathbf{2030})$	**.54**
$\bar{\Lambda}(\mathbf{2019})$	$\Lambda(\mathbf{2105})$	**4.1**			
$\Lambda(2359)$ $\Lambda(2379)$	$\Lambda(2350)$		$\Sigma(2379)$	$\Sigma(2250)$ $\Sigma(2455)^*$	
$\bar{\Lambda}(\mathbf{2369})$	$\bar{\Lambda}(\mathbf{2350})$	**0.8**	$\bar{\Sigma}(\mathbf{2379})$	$\bar{\Sigma}(\mathbf{2353})$	**1.1**
$\Lambda(\mathbf{2559})$	$\Lambda(\mathbf{2585})^*$	**0.9**			
$5\Lambda(2649)$			**3** $\Sigma(\mathbf{2649})$	$\Sigma(\mathbf{2620})$	**1.1**
			4 $\Sigma(\mathbf{2739})$		

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [19].

Table 4. The Baryons Ξ and the Baryons Ω

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Xi(\mathbf{1299})$	$\Xi(\mathbf{1318})$	**1.5**	$\Omega(\mathbf{1659})$	$\Omega(\mathbf{1672})$	0.**8**
$\Xi(\mathbf{1479})$	$\Xi(\mathbf{1530})$	**3.3**	$\Omega(2359)$	$\Omega(2250)$ $\Omega(2380)$ $\Omega(2470)$	
$\mathbf{3}\Xi(\mathbf{1659})$	$\Xi(\mathbf{1690})$	**1.8**	$\bar{\Omega}(\mathbf{2359})$	$\bar{\Omega}(\mathbf{2367})$	**0.4**
$\Xi(\mathbf{1839})$	$\Xi(\mathbf{1820})$	**1.1**	$\Omega(2879)$		
$\Xi(\mathbf{1929})$	$\Xi(\mathbf{1950})$	**1.1**	$\Omega(3619)$		
$\mathbf{2}\Xi(\mathbf{2019})$	$\Xi(\mathbf{2030})$	**1.0**	$\Omega(7019)$		
$\mathbf{2}\Xi(\mathbf{2199})$	$\Xi(\mathbf{2250})^*$	**2.3**			
$\Xi(\mathbf{2379})$	$\Xi(\mathbf{2370})^*$	**0.4**			
$\Xi(2559)$					
$5\Xi(2739)$					

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [19].

Table 5. Charmed Λ_c^+ and Bottom Λ_b^0 Baryons

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Lambda_c^+(\mathbf{2279})$	$\Lambda_c^+(\mathbf{2285})$	**0.22**	$\Lambda_b^0(\mathbf{5639})$	$\Lambda_b^0(\mathbf{5641})$	0.035
$\Lambda_c^+(2449)$ $\Lambda_c^+(2539)$	$\Lambda_c^+(2593)$ $\Lambda_c^+(2625)$		$\Lambda_b^0(10159)$		
$\bar{\Lambda}_c^+(\mathbf{2494})$	$\bar{\Lambda}_c^+(\mathbf{2609})$	**4.4**			
$\Lambda_c^+(2759)$					
$\Lambda_c^+(2969)$					
$\Lambda_c^+(6599)$					

Table 6. Charmed Strange Baryon Ξ_c, Σ_c and Ω_C

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Xi_c(2549)$	$\Xi_c(2468)$ $\Xi_c(2645)$		$\Sigma_c(2449)$ $\Sigma_c(2539)$	$\Sigma_c(2455)$ $\Sigma_c(2530)*$	
$\bar{\bar{\Xi}}_c(\mathbf{2549})$	$\bar{\bar{\Xi}}_c(\mathbf{2557})$	**0.3**	$\bar{\bar{\Sigma}}_c(\mathbf{2495})$	$\bar{\bar{\Sigma}}_c(\mathbf{2493})$	**0.08**
$\Xi_C(3169)$			$\Sigma_c(2969)$		
			$\Omega_C(\mathbf{2759})$	$\Omega_C(\mathbf{2704})$	**2.0**
			$\Omega_C(3679)$		

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [19].